LAKE ERIE SEDIMENT OXYGEN DEMAND

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ABSTRACT

During a lake-wide survey in 1963, measurements were made of depth, % organic matter, mixed sediment oxygen uptake rate, and sediment core oxygen uptake rate.

Depth had a poor, negative correlation to other variables except % organic matter, which correlated positively. Percent organic matter averaged 6.396%, and contours followed current patterns. It also had a strong correlation with mixed sediment oxygen uptake rate, which averaged 318.6 $\mu g\ O_2$/gm sediment/5 minutes. Core oxygen uptake rate, averaging 4.987 $\mu g\ O_2/cm^2$/hour, correlated strongly between incubation durations and moderately well with mixed sediment oxygen uptake rate. Cluster analysis considering all variables had an acceptable cophenetic correlation of 0.7247. The ratio of mixed sediment oxygen uptake rate to % organic matter indicated the oxidizability of sediments and was higher toward the west. Clusters and ratio values were used to define lake regions of similar sediment characteristics. Regression models of mixed sediment oxygen uptake rate versus % organic matter were computed for each cluster analysis region and ratio region. Slopes for linear regression models generally increased toward the west, indicating the increasing oxidizability of the sediments.

ACKNOWLEDGMENTS

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INTRODUCTION

The eutrophication of Lake Erie is indicated by a hypolimnetic dissolved-oxygen depletion during summer stratification. This has been of major interest ever since the possibility and eventual reality of anoxic conditions in the central basin were noted in the late 1950s.

The history of this problem is well documented (Dobson and Gilbertson 1972, Carr 1962, Carr et al. 1965), despite the absence of synoptic data prior to the 1960s. Significant changes in benthic species composition and abundance showed the consequences before anoxic conditions were directly observed. Since first noted in 1929, this oxygen depletion has become more severe, affecting a larger area more quickly after stratification (Carr 1962, Dobson and Gilbertson 1972).

Anoxic conditions in the hypolimnion present several problems, as outlined by Burns and Ross (1972b). The adverse effects upon benthic fauna are obvious, as seen in the elimination of the mayfly (Hexagenia) population, as well as in a shift toward more tolerant oligochaetes. A possible consequence, and of greater economic importance, is the replacement of more valuable fish such as blue pike and cisco by yellow perch and smelt as the basis for the lake's fishery. As the anoxic region became more widespread, difficulties were incurred by municipalities which use the lake as a water source due to the objectional taste and smell of anoxic water. Also of major concern is the increased dissolution of nutrients from sediments in the absence of oxygen, creating the possibility of a self-fertilization cycle.

Lake Erie is divided into three distinct basins that behave differently, primarily due to differences in bathymetry (Figure 1).

The western basin is extremely shallow, receives a large influx of

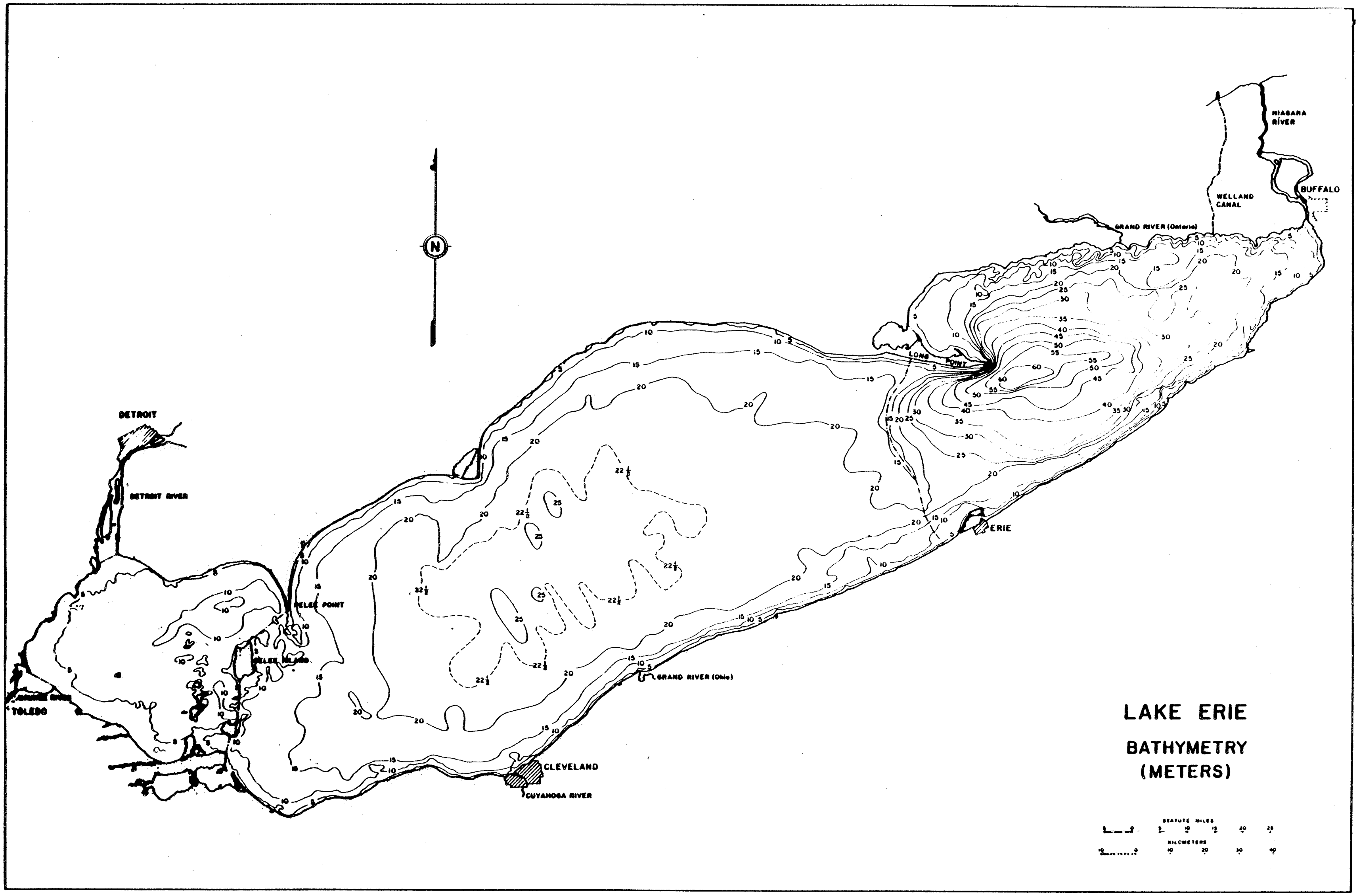

FIG. 1. Lake Erie bathymetry in meters (from Dobson and Gilbertson 1972).

nutrients and water via the Detroit, Maumee, and Raisin Rivers, and rarely stratifies (Schelske and Roth 1973). Although the western basin is highly productive with a large amount of organic matter in the sediments, the mixing due to wind and river inflow is usually sufficient to prevent anoxic conditions (Potos 1970).

Considering its vast area of 16,300 km^2, the central basin is relatively shallow, with an average depth of 18.3 meters. In spite of the long wind fetch, the basin will stratify with a thermocline occurring near 17 meters. This results in an average hypolimnion thickness of only 2.5 meters (Burns and Ross 1972b, Dobson and Gilbertson 1972). After isolation from the atmosphere, the hypolimnion is probably depleted of oxygen primarily by the sediments, due to the large sediment surface area to hypolimnion volume ratio (Lucas and Thomas 1971).

The deep eastern basin does not suffer from anoxia, even though it acts as a settling area for organic matter, due to the large hypolimnion volume and the low oxygen demand exerted by the sediments.

The longstanding belief has been that the oxygen demand in hypolimnetic water is due primarily to decomposition and bacterial oxidation within the water column of sinking organics, predominantly dead phytoplankton (Kleveno et al. 1971). However, the BOD of the overlying water is seen to be insufficient to cause anoxia in the length of time observed. The initial purpose of this study and other recent research was to find alternative mechanisms of oxygen depletion to explain this discrepancy. An attempt has also been made to quantify depletion rates.

Potos (1970) attributed oxygen depletion to respirational requirements of bacteria in the degradation of organic matter, primarily sedimented plankton, and to demand by reduced chemicals when exposed to overlying water. Citing the

occurrence of unusually high hypolimnetic current velocities of 61 cm/sec, Potos suggested that sediments can thereby be resuspended and a chemical demand created.

This theory was supported by Project Hypo, an intensive study of the central basin in 1970 (Burns and Ross 1972a). Blanton and Winklhofer (1972) reported average hypolimnetic current velocities between 2.2 and 5.6 cm/sec, but noted velocities of up to 98.5 cm/sec. They also provided additional information on the hypolimnion's dynamic nature, a detailed physical description, and documentation of volume changes. Sediment oxygen demand measured at 0.31 gm O_2/m^2/day could account for the observed depletion rates but was not assumed to be the only parameter involved.

A mechanism postulated by Kleveno et al. (1971) for sediment oxygen depletion involving benthic algae was tested in Project Hypo. The results (Braidech et al. 1972) showed that two species of algae, *Tribonema utriculon* and *Oedogonium* sp., remained viable after settling, but their contribution of oxygen was masked by stronger oxygen-demanding physical and chemical phenomena.

The conclusion that benthic algae were not of major consequence was also reached by Lucas and Thomas (1971). They did, however, observe a diurnal oxygen fluctuation. *In situ* sediment oxygen demand was calculated as 0.40 gm O_2/m^2/day.

Burns and Ross (1972c) determined an aerial uptake rate of 0.39 gm O_2/m^2/day. This value is considered most representative of Project Hypo results since it involved a basin-wide survey.

Burns (1976) asserted that oxygen depletion rates could serve as important indicators of the trophic state of Lake Erie if rates could be measured to an accuracy of 3% over a time scale of 5 years. Burns modeled hypolimnetic reoxygenation through oxygen budgets and calculated an aerial depletion rate of

0.43 gm O_2/m^2/day and a volumetric depletion rate of 0.13 gm O_2/m^3/day (3.9 mg O_2/L/month).

Dobson and Gilbertson (1972) used historic changes in oxygen concentration through the summer seasons to calculate oxygen depletion rates. They clearly show a progressive increase in the oxygen depletion rate over the last 40 years. Based on a length of stratification of 110 days, a volumetric depletion rate of 3.0 mg O_2/L/month will result in anoxic conditions. This critical rate was reached about 1960, and Carr (1962) reported anoxic conditions over 3600 km^2 in 1960.

This study attempts to elicit the relationship between organic matter and sediment oxygen uptake rate as well as to perceive the relative importance of this in overall hypolimnetic depletion.

PROCEDURES

After a preliminary study in the summer of 1962 to assess sampling methods, a lake-wide survey was completed in 1963 by the Bureau of Commercial Fisheries. Employing the research vessels Cisco and Kaho, cruises were made of the western and central basins in July and of the eastern basin in September. At each station, (Table 1, Figure 2) depth was measured and an Ekman grab sample taken. Additionally, certain physical and chemical properties of the overlying water were measured at some stations.

Immediately after the Ekman grab was retrieved, about 0.25 gm (dry weight) of the top few millimeters of sediment was skimmed off, placed in a 32.5-mL D.O. bottle with water of known saturated oxygen concentration, stoppered by an oxygen electrode, and kept in suspension using a magnetic stirrer. Oxygen consumption for the mixed sediment was monitored over 5 minutes. These values

TABLE 1. Sampling locations and dates.

STATION #	LATITUDE	LONGITUDE	DATE
1.	41°35'45"	82°50'00"	7/ 9/63
2.	41°39'15"	82°52'30"	7/ 9/63
3.	41°43'55"	82°53'00"	7/ 9/63
4.	41°48'00"	82°53'55"	7/ 9/63
5.	41°52'45"	82°49'10"	7/ 9/63
6.	41°57'05"	82°44'10"	7/ 9/63
7.	41°52'45"	82°44'40"	7/ 9/63
8.	41°48'30"	82°45'10"	7/ 9/63
9.	41°43'00"	82°46'00"	7/ 9/63
10.	41°38'25"	82°45'50"	7/10/63
11.	41°33'40"	82°45'45"	7/10/63
12.	41°33'45"	82°42'30"	7/10/63
13.	41°32'40"	82°40'00"	7/10/63
14.	41°36'00"	82°38'35"	7/10/63 9/ 5/63
15.	41°40'15"	82°35'20"	7/10/63
16.	41°44'45"	82°34'45"	7/10/63
17.	41°48'25"	82°34'40"	7/10/63
18.	41°53'00"	82°34'35"	7/10/63
19.	41°57'45"	82°34'30"	7/10/63
20.	42°00'20"	82°26'50"	7/11/63
21.	41°56'00"	82°26'25"	7/11/63
22.	41°51'40"	82°26'05"	7/11/63
23.	41°47'00"	82°26'45"	7/11/63
24.	41°42'50"	82°27'50"	7/11/63
25.	41°38'25"	82°29'00"	7/11/63
26.	41°34'00"	82°30'10"	7/11/63
27.	41°29'50"	82°31'10"	7/11/63
28.	41°28'00"	82°22'15"	7/11/63
29.	41°26'00"	82°27'45"	7/11/63
30.	41°25'30"	82°32'20"	7/11/63
31.	41°32'05"	82°22'30"	7/12/63
32.	41°36'20"	82°22'30"	7/22/63

(continued)

TABLE 1. (continued)

STATION #	LATITUDE	LONGITUDE	DATE
33.	41°41'30"	82°22'30"	7/12/63
34.	41°45'00"	82°21'40"	7/12/63
35.	41°49'15"	82°20'25"	7/12/63
36.	41°53'20"	82°19'20"	7/12/63
37.	41°57'50"	82°18'10"	7/12/63
38.	42°02'00"	82°17'05"	7/12/63
39.	42°05'55"	82°14'15"	7/12/63
40.	42°08'10"	82°08'50"	7/12/63
41.	42°10'45"	82°04'10"	7/12/63
42.	42°09'30"	81°56'30"	7/12/63
43.	42°05'20"	81°58'10"	7/13/63
44.	42°01'00"	81°59'40"	7/13/63
45.	41°57'00"	82°01'15"	7/13/63
46.	41°52'55"	82°02'40"	7/13/63
47.	41°48'30"	82°04'10"	7/13/63
48.	41°44'30"	82°05'45"	7/13/63
49.	41°40'20"	82°07'15"	7/13/63 9/ 5/63
50.	41°36'00"	82°08'40"	7/22/63
51.	41°32'15"	82°03'30"	7/13/63
52.	41°31'50"	82°10'15"	7/13/63
53.	41°35'15"	81°57'15"	7/15/63
54.	41°39'25"	81°55'40"	7/22/63
55.	41°43'40"	81°54'25"	7/15/63 9/ 5/63
56.	41°47'35"	81°52'40"	7/15/63
57.	41°51'50"	81°51'00"	7/15/63
58.	41°56'00"	81°49'30"	7/15/63
59.	42°00'00"	81°47'55"	7/15/63
60.	42°04'10"	81°46'15"	7/15/63
61.	42°08'45"	81°44'40"	7/15/63
62.	42°11'25"	81°49'00"	7/15/63
63.	42°13'15"	81°44'00"	7/16/63

(continued)

TABLE 1. (continued)

STATION #	LATITUDE	LONGITUDE	DATE
64.	42°12'00"	81°34'55"	7/16/63
65.	42°10'40"	81°26'20"	7/16/63
66.	42°04'20"	81°29'20"	7/16/63
67.	41°58'10"	81°32'10"	7/16/63
68.	41°52'00"	81°35'10"	7/16/63
69.	41°45'50"	81°38'10"	7/16/63
			9/ 5/63
70.	41°39'40"	81°41'10"	7/17/63
71.	41°33'30"	81°44'10"	7/17/63
72.	41°35'50"	81°38'10"	7/17/63
73.	41°41'30"	81°33'40"	7/17/63
74.	41°47'00"	81°28'50"	7/17/63
			9/ 5/63
75.	41°52'30"	81°24'20"	7/17/63
76.	41°58'00"	81°19'30"	7/17/63
77.	42°02'00"	81°16'10"	7/17/63
78.	42°06'45"	81°12'30"	7/17/63
79.	42°03'15"	81°04'40"	7/17/63
80.	41°59'40"	80°57'30"	7/17/63
81.	41°56'15"	80°50'20"	7/17/63
82.	41°54'00"	81°00'00"	7/17/63
			9/ 5/63
83.	41°57'45"	81°00'00"	7/18/63
			7/21/63
84.	42°04'10"	81°00'00"	7/18/63
85.	42°10'25"	81°00'00"	7/18/63
86.	42°17'00"	81°00'00"	7/18/63
87.	42°23'10"	81°00'00"	7/18/63
88.	42°29'10"	81°02'55"	7/18/63
89.	42°34'20"	81°07'30"	7/18/63
90.	42°33'45"	81°16'00"	7/18/63
91.	42°27'45"	81°18'35"	7/19/63
92.	42°21'50"	81°21'20"	7/19/63

(continued)

TABLE 1. (continued)

STATION #	LATITUDE	LONGITUDE	DATE
93.	42°15'50"	81°23'55"	7/19/63
94.	42°15'45"	81°31'10"	7/19/63
95.	42°22'00"	81°38'45"	7/19/63
96.	42°26'15"	81°32'30"	7/19/63
97.	42°30'40"	81°26'00"	7/19/63
98.	42°35'00"	81°20'00"	7/19/63
99.	42°34'55"	80°56'30"	7/20/63
100.	42°32'40"	80°48'40"	7/20/63
101.	42°26'20"	80°46'15"	7/20/63
102.	42°20'25"	80°43'20"	7/20/63
103.	42°18'00"	80°32'40"	7/20/63
104.	42°14'15"	80°40'10"	7/20/63
105.	42°11'45"	80°33'00"	7/20/63
106.	42°08'15"	80°37'20"	7/20/63
107.	42°05'15"	80°33'15"	7/20/63
108.	42°02'50"	80°30'20"	7/20/63 9/ 6/63
109.	42°02'15"	80°34'50"	7/21/63
110.	42°02'40"	80°42'00"	7/21/63
111.	42°06'10"	80°49'45"	7/21/63
112.	41°55'45"	81°10'40"	7/21/63
113.	41°51'20"	81°17'40"	7/21/63
114.	41°34'50"	81°51'20"	7/22/63
115.	42°09'00"	80°27'50"	9/ 6/63
116.	42°15'20"	80°25'15"	9/ 6/63
117.	42°19'50"	80°23'20"	9/ 6/63
C 9.	42°29'45"	80°18'45"	9/ 6/63
118.	42°23'00"	80°18'45"	9/ 6/63
C10.	42°16'30"	80°18'40"	9/ 6/63
119.	42°10'00"	80°18'45"	9/ 6/63
120.	42°10'30"	80°11'35"	9/ 7/63
121.	42°13'40"	80°15'40"	9/ 7/63
122.	42°19'25"	80°12'50"	9/ 7/63
123.	42°25'00"	80°09'50"	9/ 7/63
124.	42°31'00"	80°07'00"	9/ 7/63

(continued)

TABLE 1. (continued)

STATION #	LATITUDE	LONGITUDE	DATE
C25.	42°21'00"	80°06'20"	9/ 7/63
C 4.	42°15'00"	80°08'00"	9/ 7/63
125.	42°12'00"	80°05'00"	9/ 7/63
C 5.	42°17'15"	79°58'30"	9/ 8/63
C 7.	42°30'00"	79°55'50"	9/ 8/63
126.	42°32'45"	80°02'25"	9/ 8/63
127.	42°34'25"	80°01'30"	9/ 8/63
128.	42°39'00"	80°13'00"	9/ 8/63
129.	42°43'00"	80°13'00"	9/ 8/63
130.	42°46'15"	80°12'30"	9/ 8/63
131.	42°42'55"	80°07'00"	9/ 9/63
132.	42°39'00"	80°02'00"	9/ 9/63
133.	42°34'30"	79°56'05"	9/ 9/63
134.	42°30'00"	79°50'00"	9/ 9/63
135.	42°23'00"	79°50'00"	9/ 9/63
136.	42°16'10"	79°50'00"	9/ 9/63
137.	42°25'00"	79°38'00"	9/ 9/63
138.	42°30'00"	79°24'00"	9/ 9/63
139.	42°34'20"	79°23'45"	9/10/63
140.	42°34'20"	79°33'20"	9/10/63
141.	42°34'20"	79°42'30"	9/10/63
142.	42°38'45"	79°50'00"	9/10/63
143.	42°43'00"	79°57'30"	9/10/63
144.	42°43'00"	79°47'00"	9/10/63
145.	42°43'00"	79°38'30"	9/10/63
146.	42°48'45"	79°36'00"	9/10/63
147.	42°48'15"	79°28'10"	9/11/63
148.	42°43'20"	79°18'30"	9/11/63
149.	42°48'25"	79°09'00"	9/11/63
150.	42°49'45"	79°00'20"	9/11/63
151.	42°46'15"	78°57'00"	9/11/63
152.	42°41'20"	79°06'35"	9/11/63
153.	42°35'00"	79°15'00"	9/11/63
154.	42°38'00"	79°23'40"	9/11/63
155.	42°38'00"	79°32'00"	9/11/63

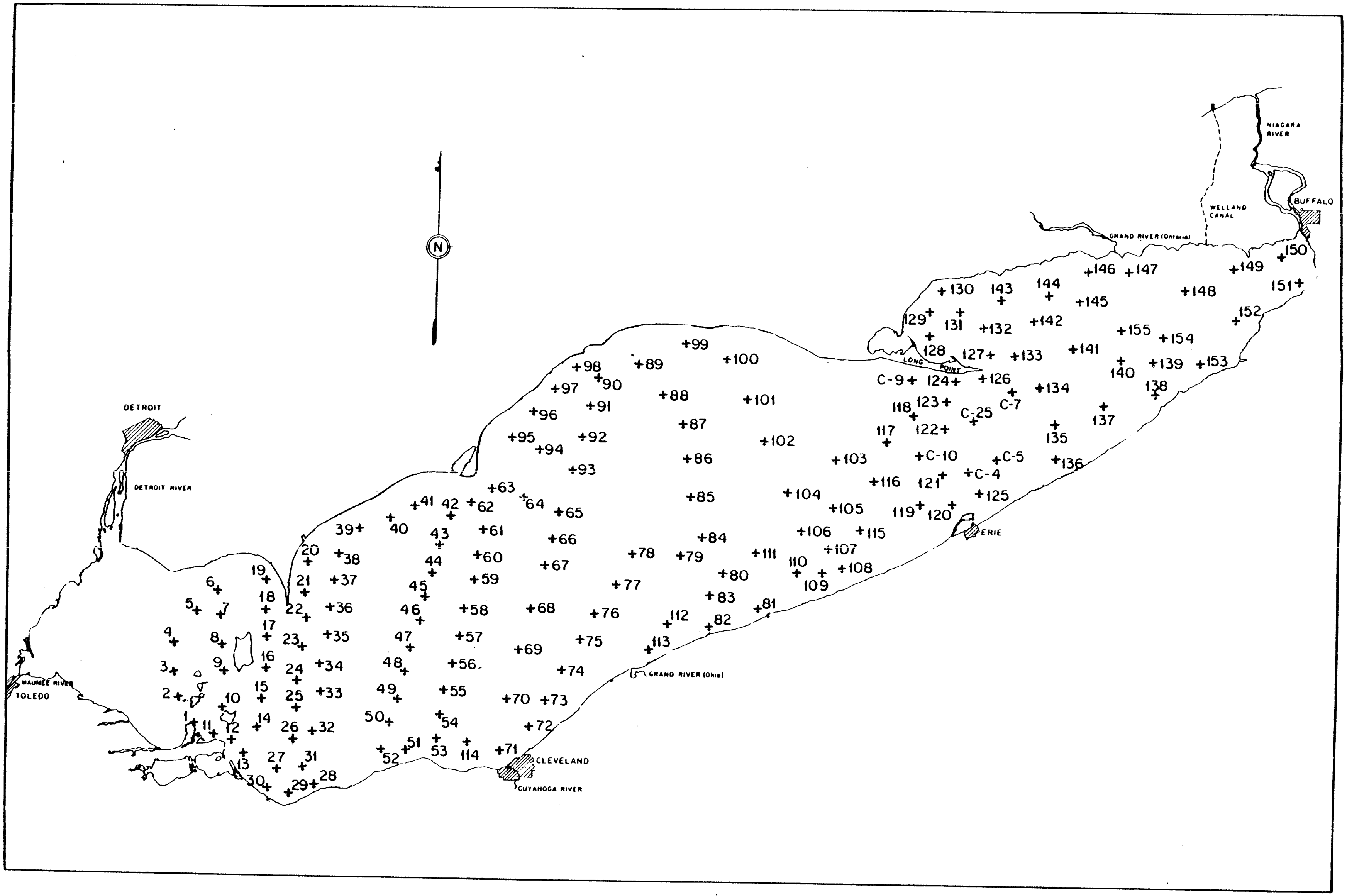

FIG. 2. Station locations in Lake Erie, 1963.

are referred to as mixed sediment oxygen uptake rates. The sediment was then filtered from the water, dried at 60°C, and weighed. Organic content was determined by ashing at 600°C.

A separate portion of the surficial sediment was centrifuged to the bottom of several 50-mL vials; the vial sides were washed and recentrifuged, and the supernatant decanted. A known volume and oxygen concentration of oxygen-saturated water was added and the samples incubated for 2, 4, and 6 hours at 20°C. Incubation water was then siphoned with a syringe into 5-mL glass-stoppered vials used as micro D.O. bottles. Oxygen consumption values determined by this procedure are referred to as core oxygen uptake rates. Possible oxygen contamination was not considered to be as critical as for other procedures, since this would only further minimize an intentionally conservative measure of oxygen uptake.

The Winkler method was used for all D.O. determinations, with the micro D.O. bottles having 2 mL titrated with 0.0025 N sodium thiosulfate.

Analysis using the University of Michigan's MIDAS statistics program was done on only those stations with complete data for depth, % organic matter, mixed sediment oxygen uptake, and core oxygen uptakes (Table 2). Variables were plotted by station location and contours drawn. Correlation coefficients were calculated between all variables (Table 3) and, based on these results, mixed sediment oxygen uptake rates were plotted against % organic matter.

In order to further stratify the data, several cluster analyses were done using all variables. Additionally, the ratio of mixed sediment oxygen uptake to % organic content was calculated for each station. Regions determined by clustering and by similarity of ratio values were then used to plot % organic matter versus mixed uptake rate separately. Least square regression models were calculated for each region.

TABLE 2. Depth, percent organic matter, oxygen demand of mixed and unmixed sediments, and ratio of mixed sediment oxygen uptake rate to percent organic matter for Lake Erie, 1963.

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [μg O_2] [gm sed/5 min]	CORE UPTAKE RATE [μg O_2/cm^2/hr] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] [100(% org)]
2.	9.	8.82	724.	8.49	5.75	5.19	6.48	0.82
3.	10.	8.28	701.	12.35	6.86	5.65	8.29	0.85
4.	10.	7.67	558.	8.29	5.91	3.82	6.01	0.73
5.	11.	5.92	528.	8.51	6.71	5.38	6.87	0.89
6.	11.	5.08	452.	8.05	6.01	4.53	6.20	0.89
8.	9.	7.14	475.	8.29	5.43	5.58	6.43	0.67
9.	11.	7.20	742.	7.84	6.33	4.49	6.22	1.03
10.	9.	6.71	634.	7.08	5.08	4.16	5.44	0.94
11.	7.	7.13	539.	5.94	5.97	5.20	5.70	0.76
12.	10.	4.22	340.	8.18	7.01	5.08	6.76	0.81
13.	11.	7.54	557.	7.89	6.33	5.97	6.73	0.74
14.	13.	6.97	647.	5.66	4.00	5.32	4.99	0.93
14.	20.	7.32	329.	3.33	4.03	3.62	3.66	0.45
15.	12.	5.93	315.	8.30	5.14	5.62	6.35	0.53
16.	11.	5.52	331.	10.15	7.60	4.89	7.55	0.60
17.	9.	8.76	87.	7.88	6.62	5.48	6.66	0.10
18.	10.	6.48	259.	8.70	7.78	5.97	7.48	0.40
19.	10.	5.68	448.	10.20	6.95	6.76	7.97	0.79
20.	13.	1.27	26.	5.34	3.09	3.05	3.83	0.20
21.	12.	5.99	438.	8.76	7.42	6.18	7.45	0.73
22.	11.	1.87	50.	10.24	6.18	4.80	7.07	0.27
23.	11.	4.56	271.	9.41	6.81	6.12	7.45	0.59
25.	13.	7.36	478.	8.34	7.51	6.17	7.34	0.65
26.	13.	6.72	563.	7.93	6.57	6.48	6.99	0.84
27.	13.	8.70	723.	8.95	7.73	6.48	7.72	0.83
28.	12.	8.66	602.	9.62	7.56	6.35	7.84	0.70

(continued)

TABLE 2. (Continued).

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [$\mu g\ O_2$] [gm sed/5 min]	CORE UPTAKE RATE [$\mu g\ O_2/cm^2/hr$] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] [100(% org)]
29.	10.	7.17	470.	8.76	5.34	5.17	6.42	0.66
30.	9.	4.63	300.	9.12	6.64	5.31	7.02	0.65
31.	13.	8.61	516.	6.95	5.65	6.69	6.10	0.60
32.	14.	0.42	8.	3.92	4.05	2.49	3.49	0.19
33.	14.	5.88	149.	6.37	6.38	5.55	6.10	0.25
34.	15.	6.90	253.	8.92	5.90	4.91	6.58	0.37
35.	16.	5.51	144.	9.71	6.95	6.52	7.73	0.26
36.	17.	8.33	352.	9.58	7.04	6.84	7.82	0.42
37.	19.	9.32	730.	10.22	5.84	4.77	6.94	0.78
38.	20.	9.88	533.	8.56	6.37	5.95	6.96	0.54
39.	20.	9.78	411.	7.30	6.83	6.34	6.82	0.42
40.	20.	9.66	465.	11.05	7.00	5.47	7.84	0.48
41.	20.	8.70	404.	8.26	5.77	5.90	6.64	0.46
43.	19.	1.96	14.	2.14	1.72	1.43	1.76	0.07
44.	22.	8.65	586.	7.04	6.23	5.73	6.33	0.68
45.	22.	9.02	623.	7.30	6.11	4.66	6.02	0.69
46.	22.	9.98	464.	7.25	5.69	4.85	5.93	0.46
47.	22.	9.64	485.	8.02	5.48	4.95	6.15	0.50
48.	20.	9.25	612.	7.81	6.23	5.42	6.49	0.66
49.	19.	9.06	603.	6.67	5.30	5.14	5.70	0.67
49.	18.	9.56	417.	2.93	3.79	4.14	3.62	0.44
50.	17.	6.88	555.	7.81	6.95	6.16	6.97	0.81
50.	17.	7.27	434.	7.68	4.71	4.99	5.79	0.60
51.	17.	9.34	754.	9.41	6.95	5.57	7.31	0.81
52.	16.	6.94	470.	9.73	6.17	5.92	7.27	0.68
53.	18.	10.07	509.	4.61	4.16	3.88	4.22	0.51

(continued)

TABLE 2. (Continued).

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [$\mu g\ O_2$] [gm sed/5 min]	CORE UPTAKE RATE [$\mu g\ O_2/cm^2/hr$] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] [100(% org)]
53.	17.	6.80	516.	7.99	6.11	3.56	5.89	0.76
54.	20.	10.37	691.	3.45	4.16	3.04	3.55	0.67
55.	22.	9.93	685.	6.98	4.57	3.82	5.12	0.69
55.	21.	9.46	706.	5.92	4.34	4.23	4.83	0.75
56.	23.	9.41	423.	6.26	4.34	3.66	4.75	0.45
57.	24.	9.48	347.	6.84	5.81	3.24	5.30	0.37
58.	24.	10.73	382.	5.37	3.27	2.93	3.86	0.36
63.	22.	9.60	221.	2.86	3.52	3.22	3.20	0.23
64.	24.	9.37	355.	6.91	4.21	3.60	4.91	0.38
67.	24.	8.42	559.	8.48	4.60	5.31	6.13	0.66
68.	23.	10.19	514.	6.59	4.79	5.26	5.55	0.50
69.	21.	10.76	648.	3.32	3.40	3.58	3.43	0.60
72.	17.	1.34	8.	3.44	2.26	1.99	2.56	0.06
74.	20.	10.75	600.	3.75	4.46	3.81	4.01	0.56
75.	22.	9.53	568.	9.05	5.42	4.62	6.36	0.60
76.	23.	9.06	437.	8.45	6.74	8.74	7.98	0.48
77.	22.	7.37	505.	7.90	5.44	4.60	5.98	0.69
78.	23.	5.72	270.	7.32	5.42	4.44	5.73	0.47
79.	22.	5.43	258.	16.19	5.10	3.70	8.33	0.48
80.	22.	8.42	437.	5.21	5.08	3.95	4.75	0.52
80.	22.	9.64	420.	5.16	6.39	4.79	5.45	0.44
81.	17.	3.76	164.	8.89	6.76	4.23	6.63	0.44
82.	19.	8.08	418.	6.04	4.98	4.76	5.26	0.52
82.	17.	9.67	448.	4.88	2.79	2.73	3.47	0.46
83.	22.	8.19	571.	7.28	4.94	4.89	5.70	0.70
83.	21.	10.19	314.	7.13	5.70	4.38	5.74	0.31

(continued)

TABLE 2. (Continued).

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [μg O_2] [gm sed/5 min]	CORE UPTAKE RATE [μg $O_2/cm^2/hr$] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] [100(% org)]
84.	22.	5.92	274.	7.46	5.53	5.74	6.24	0.46
85.	22.	5.05	199.	7.43	5.07	4.06	5.52	0.39
86.	23.	4.86	151.	5.72	4.20	3.71	4.54	0.31
87.	20.	4.04	56.	5.21	4.15	3.23	4.20	0.14
91.	20.	8.35	171.	4.51	5.27	4.02	4.60	0.20
92.	22.	7.96	226.	6.27	4.46	4.20	4.98	0.28
94.	22.	8.85	318.	4.24	4.12	3.84	4.07	0.36
96.	20.	8.39	249.	4.83	4.54	3.56	4.31	0.30
97.	18.	3.14	15.	3.37	2.91	2.43	2.90	0.05
99.	17.	1.06	12.	6.22	4.87	3.46	4.85	0.11
100.	18.	2.34	113.	3.88	2.95	7.98	4.94	0.48
101.	19.	6.18	129.	12.84	4.15	5.67	7.55	0.21
102.	21.	2.00	66.	7.88	6.54	5.04	6.49	0.33
103.	20.	1.28	48.	11.52	5.24	4.52	7.09	0.38
104.	21.	1.75	36.	8.81	3.63.	6.82	6.42	0.21
107.	19.	3.62	127.	1.90	7.09	3.34	4.11	0.35
108.	14.	3.40	119.	8.41	5.36	4.56	6.11	0.35
109.	13.	6.38	444.	5.68	4.35	4.87	4.97	0.70
110.	20.	7.37	309.	5.86	5.04	4.25	5.05	0.42
111.	23.	2.56	77.	5.22	3.37	2.84	3.81	0.30
112.	21.	9.52	428.	6.45	6.58	4.19	5.74	0.45
113.	19.	7.68	509.	8.17	6.49	5.07	6.58	0.66
114.	19.	7.84	463.	6.57	6.08	4.65	5.77	0.59
115.	22.	1.77	65.	2.20	4.38	1.80	2.79	0.37
116.	18.	3.46	136.	2.51	3.38	2.49	2.79	0.39
117.	15.	0.25	19.	1.53	2.14	0.96	1.54	0.76

(continued)

TABLE 2. (Continued).

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [μg O_2] [gm sed/5 min]	CORE UPTAKE RATE [μg $O_2/cm^2/hr$] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] / [100(% org)]
118.	24.	1.40	26.	3.96	1.31	1.94	2.40	0.19
120.	18.	4.72	162.	3.20	4.37	4.39	3.99	0.34
122.	27.	1.14	38.	1.33	5.00	2.14	2.82	0.33
123.	38.	6.01	37.	2.17	2.48	1.80	2.15	0.06
124.	42.	6.41	313.	4.16	5.03	3.94	4.38	0.49
127.	42.	3.64	81.	2.98	2.92	2.40	2.77	0.22
128.	9.	2.00	105.	3.91	2.59	1.90	2.80	0.53
129.	9.	2.91	110.	3.04	3.24	2.46	2.91	0.38
131.	13.	4.16	110.	3.20	1.19	1.90	2.10	0.26
132.	36.	5.89	170.	0.74	2.02	3.24	2.00	0.29
133.	53.	6.96	132.	0.51	1.55	1.80	1.29	0.19
134.	60.	3.04	578.	3.01	3.65	2.36	3.01	1.90
135.	40.	8.26	80.	1.90	1.67	1.17	1.58	0.10
136.	17.	4.80	121.	4.95	4.22	3.49	4.22	0.25
137.	38.	8.18	88.	1.62	1.48	1.57	1.56	0.11
138.	18.	4.97	218.	2.54	4.01	3.46	3.34	0.44
139.	31.	7.66	43.	0.44	2.87	2.38	1.90	0.06
140.	46.	8.95	327.	4.95	2.97	3.22	3.71	0.37
141.	55.	9.16	213.	4.47	3.60	3.10	3.72	0.23
142.	42.	9.32	154.	3.08	2.95	2.48	2.84	0.17
143.	23.	2.77	35.	1.36	1.52	2.16	1.68	0.13
145.	27.	5.40	61.	3.54	2.76	3.34	3.21	0.11
147.	19.	2.10	26.	3.20	3.44	3.40	3.35	0.12
148.	23.	4.21	103.	3.45	3.56	2.89	3.30	0.24
149.	18.	1.93	55.	5.38	3.05	2.23	3.55	0.28
150.	46.	3.09	47.	3.45	3.72	3.14	3.44	0.15

(continued)

TABLE 2. (Continued).

STATION	DEPTH [METERS]	% ORG	MIXED UPTAKE RATE [μg O_2] [gm sed/5 min]	CORE UPTAKE RATE [μg $O_2/cm^2/hr$] 2 hr	4 hr	6 hr	avg	RATIO [mixed uptake] [100(% org)]
151.	11.	1.02	38.	0.36	0.68	1.42	0.82	0.37
152.	15.	1.12	25.	1.64	1.70	2.33	1.89	0.22
153.	20.	6.85	270.	6.73	3.29	3.39	4.47	0.39
154.	27.	7.52	205.	4.84	3.77	2.29	3.63	0.27
155.	29.	6.82	197.	2.93	3.85	3.76	3.51	0.29
C-5.	27.	4.86	31.	1.74	2.22	2.36	2.11	0.06
C-7.	62.	8.25	446.	4.20	3.11	2.46	3.26	0.54
C-9.	14.	0.54	21.	0.84	0.49	0.39	0.57	0.39

TABLE 3. Correlation of depth, percent organic matter, oxygen uptake rates, and ratio of mixed sediment oxygen uptake rate to percent organic matter in Lake Erie, 1963.

VARIABLE	Depth	% Org	Mixed	2 Hr Core	4 Hr Core	6 Hr Core	Avg Core	Ratio
Depth [meters]	1.000							
% Organic	0.119	1.000						
Mixed Uptake [$\mu g O_2$/gm sed/5 min]	-.1736	0.7213	1.0000					
2-hr Core Uptake [$\mu g O_2/cm^2/hr$]	-.4083	0.2661	0.4684	1.0000				
4-hr Core Uptake [$\mu g O_2/cm^2/hr$]	-.4101	0.3528	0.5443	0.7572	1.0000			
6-hr Core Uptake [$\mu g O_2$/cm2/hr]	-.3964	0.3648	0.5227	0.7366	0.7924	1.0000		
Average Core Uptake [$\mu g O_2/cm^2/hr$]	-.4412	0.3425	0.5471	0.9429	0.9064	0.8894	1.0000	
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	-.1941	0.2646	0.7948	0.3991	0.4716	0.4076	0.4583	1.0000

N = 138; Degrees Freedom = 136; R @ .01 = 0.2186

Scatter plots were also obtained by region for depth and % organic matter against core oxygen uptake and for depth versus mixed sediment oxygen uptake.

RESULTS

Sampling depths ranged from 7 to 62 meters (Table 4), with an average of 20.5 meters, which is representative of the major portion of the central basin (Figure 1). Depth had a poor negative correlation to all of the other variables except % organic matter which had a positive correlation (Table 3). Scatter plots of depth versus core and mixed sediment oxygen uptake rates also indicated a lack of strong correlation.

Percentage of organic matter varied from 0.25 to 10.76% and averaged 6.396% (Table 4). This reflects a general trend away from shore (Figure 3), with the greatest values in the deeper basins and a scouring effect lowering values near shore, as well as off Pt. Pelee and Pte. Aux Pins. There is, for the most part, a paucity of organic content in sediments of the eastern third of the central basin. The south shore of the central basin is characterized by higher values offshore, extending from Sandusky, Ohio, to east of Erie, Pennsylvania. Average values are seen in the western basin, while the eastern basin exhibits higher values in deep regions and very low values in the far eastern end. Percentage of organic matter showed good correlation (0.7213) with mixed sediment oxygen uptake and less correlation to core oxygen uptake rates and depth (Table 3).

Mixed sediment oxygen uptake had an equally broad range, from 8. to 754. $\mu g\ O_2/gm$ sediment/5 minutes, averaging 318.6 $\mu g\ O_2/gm$ sediment/5 minutes (Table 4). Contours (Figure 4) followed those of % organic matter fairly closely, with the highest uptake occurring in regions of high organic content. For a

TABLE 4. Statistical data on depth, oxygen demand, percent organic matter, and ratio of mixed sediment oxygen uptake rate to percent organic matter for Lake Erie sediments, 1963.

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
Depth [meters]	7.	62.	20.5	10.0	1.942	4.596
% Organic	0.25	10.76	6.396	2.855	-0.503	-0.872
Mixed Uptake [μgO_2/gm sed/5 min]	8.	754.	318.6	219.8	0.182	-1.211
2-hr Core Uptake [$\mu gO_2/cm^2/hr$]	0.36	16.19	6.065	2.916	0.167	-0.050
4-hr Core Uptake [$\mu gO_2/cm^2/hr$]	0.49	7.78	4.742	1.710	-0.330	-0.650
6-hr Core Uptake [$\mu gO_2/cm^2/hr$]	0.39	8.74	4.153	1.535	0.045	-0.297
Average Core Uptake [$\mu gO_2/cm^2/hr$]	0.57	8.33	4.987	1.888	-0.269	-0.910
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.05	1.90	0.468	0.262	1.239	4.926

N = 138

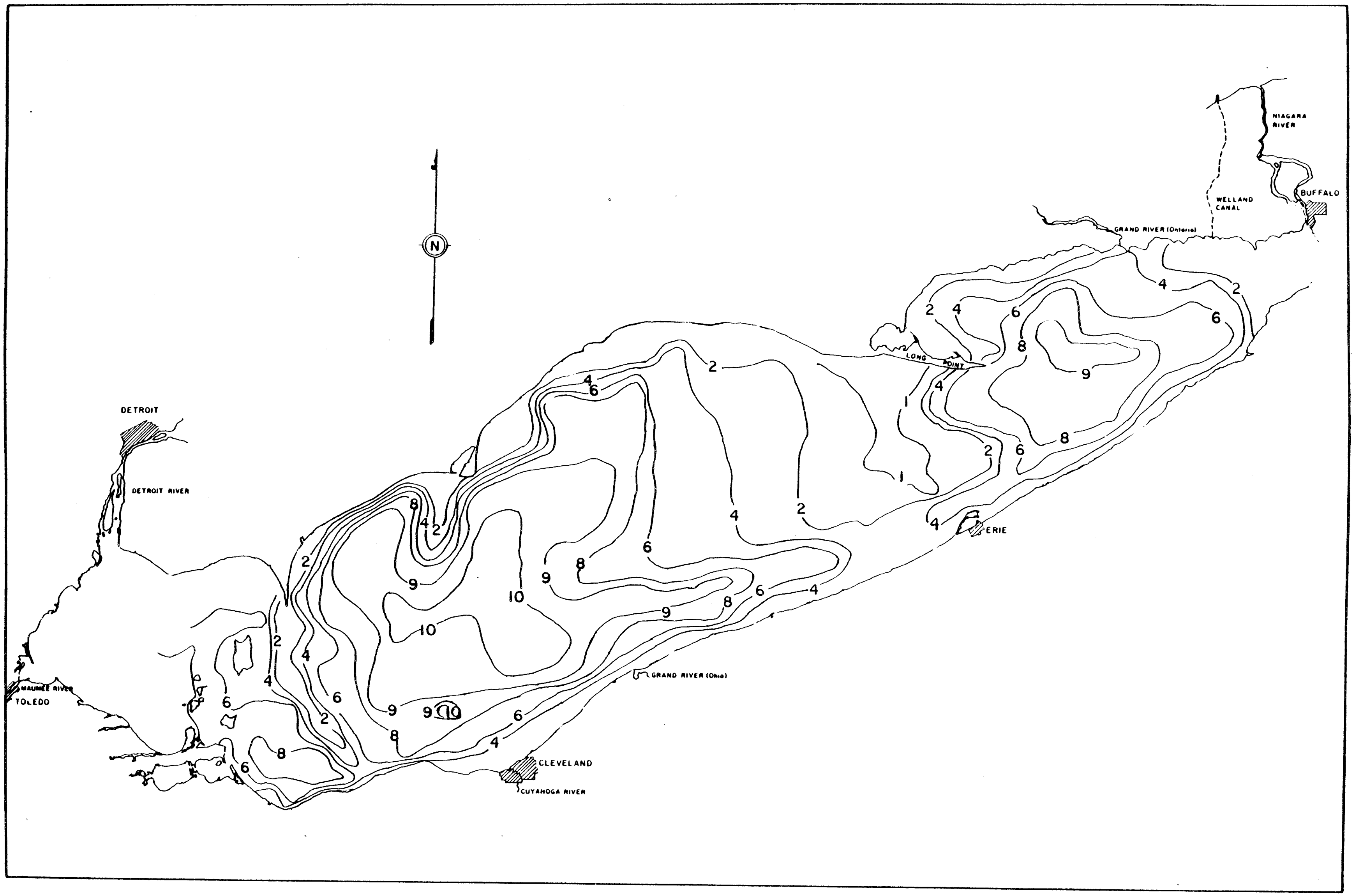

FIG. 3. Percentage of organic matter in sediments of Lake Erie, 1963.

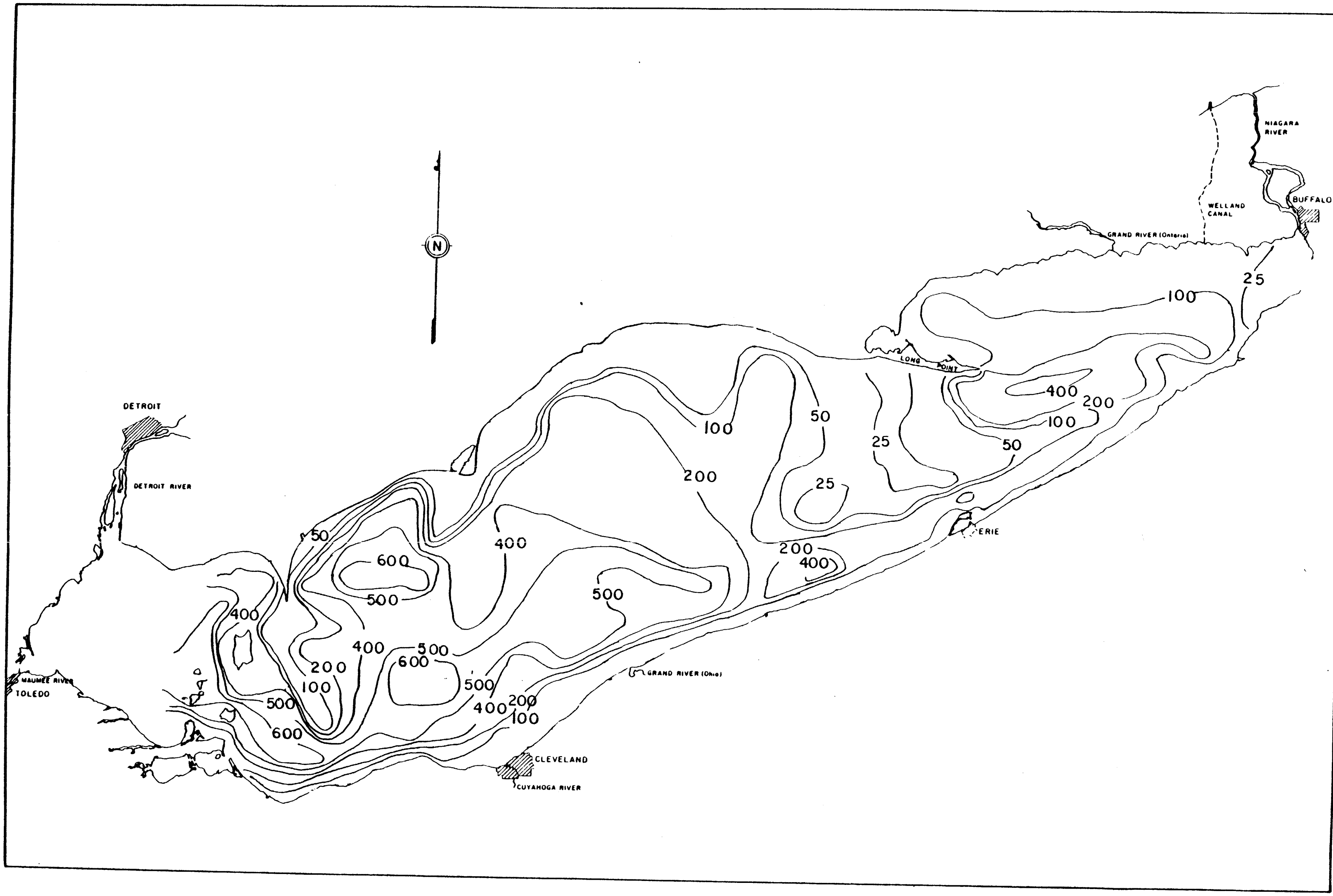

FIG. 4. Mixed sediment oxygen uptake rate ($\mu g\ O_2$ consumed/gm sediment/5 minutes) in Lake Erie, 1963.

given organic content, however, uptake was highest toward the west. This relationship can be seen by comparing mixed sediment oxygen uptake rates of 400, 500, and over 600 μg O_2/gm sediment/5 minutes for the eastern, central, and western basins, respectively, all in areas of about 9% organic matter. Compared with % organic matter, mixed sediment oxygen uptake rates had less correlation to the other variables (Table 3).

Core oxygen uptake rates ranged from 0.36 to 16.19 μg O_2/cm^2/hr for 2-hr incubation but became more conservative with longer incubation durations. Averaged core oxygen uptake rates for each station ranged from 0.57 to 8.33 μg O_2/cm^2/hr, with a mean of 4.987 μg O_2/cm^2/hr (Table 4). Core oxygen uptake rates correlated only moderately well (0.4684-0.5471) with mixed sediment oxygen uptake rates, and poorly with other variables (Table 3). There was, however, excellent correlation (0.7366-0.9429) between uptake rates of various incubation times. Contours of average core oxygen uptake rates (Figure 5) were fairly consistent with contours of % organic matter and mixed sediment oxygen uptake rate, but scatter plots of core oxygen uptake rates versus % organic matter and depth showed no relationship between them.

Cluster analysis is a statistical technique done by computer in which similarity of stations is determined by comparing relative proximity after plotting stations in N-dimensional space, where N is the number of variables characterizing each station. The cluster analysis that yielded the best grouping, or highest cophenetic correlation (0.7247), was standard Euclidean with averaged distances. While this optimal case exhibits only fair clustering, the groupings thus determined did fall into distinct regions (Figure 6) within the lake, with a few excluded stations that did not exhibit similarity to any others. Cluster regions had similar sediment characteristics based on depth, percent organic matter, mixed sediment oxygen uptake rate, core

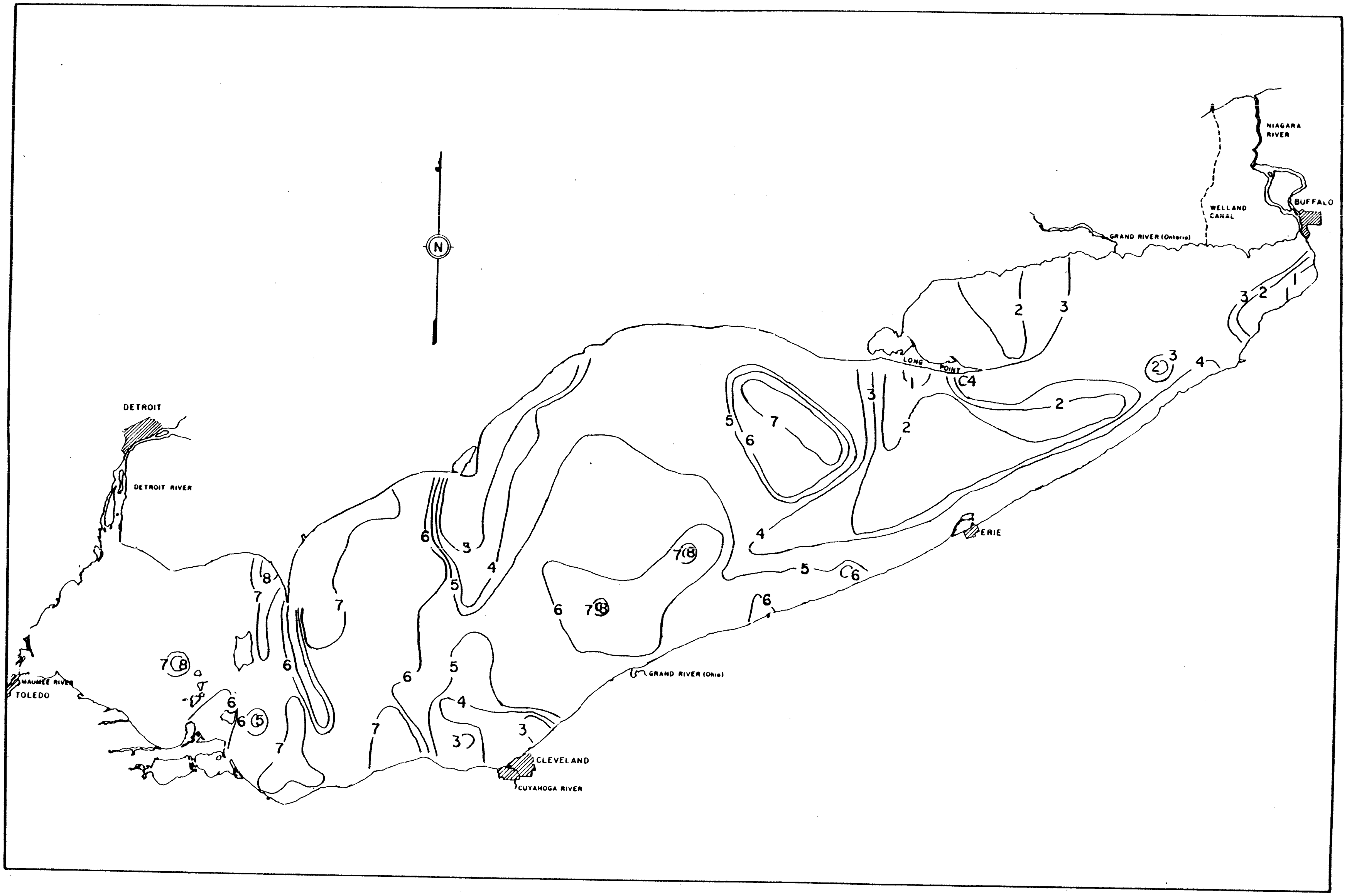

FIG. 5. Average sediment core oxygen uptake rate (μg O_2 consumed/cm^2/hour) in Lake Erie, 1963.

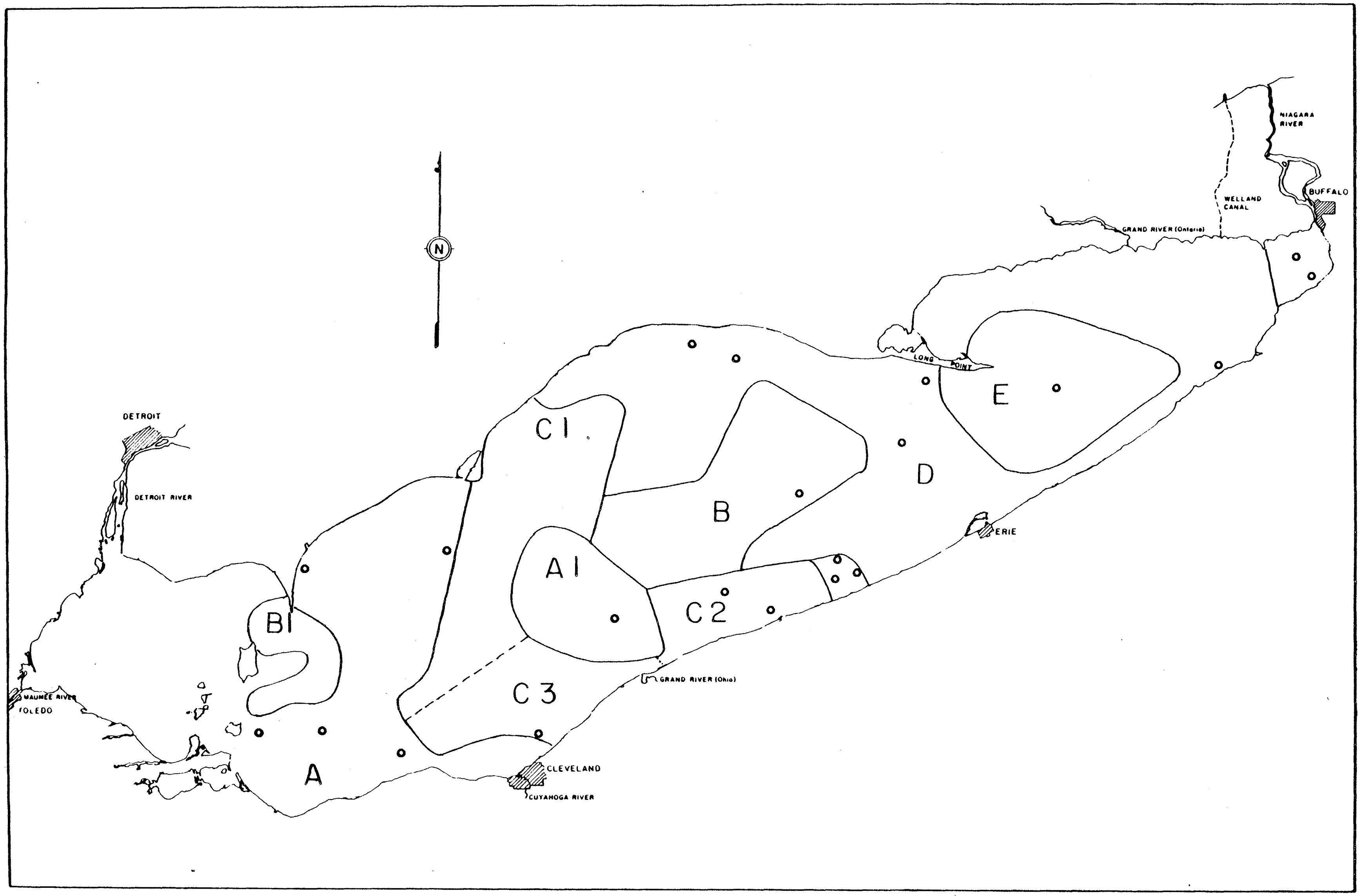

FIG. 6. Regions of similar sediment characteristics as determined by cluster analysis.

oxygen uptake rates, and ratio of mixed sediment oxygen uptake rate to percent organic matter.

Ratio values, a variable dependent on % organic and mixed uptake rate, rarely had a value greater than one. This value was computed by dividing the mixed sediment oxygen uptake rate by 100 times the % organic matter for each station. These values, therefore, show the degree of oxidizability of sediments or, in other words, the oxygen demand of sediment with a certain % organic matter. Curiously, ratio values (Figure 7) showed a low correlation (0.2646) to % organic matter (Table 3). These values were used to divide the lake into regions of similar sediment oxidizability (Figure 8). Highest values, >0.70, were found in the western basin and the southwest corner of the central basin (Regions 1 and 2). These graded into those between 0.70 and 0.40 in Region 3, while values in the high 0.60s were found in Region 4. Regions 5 and 6 were both characterized by ratio values generally less than 0.40.

Scatter plots of mixed sediment oxygen uptake versus % organic matter based on grouping by cluster analysis and ratio similarity exhibited either a tight clumping or a significant regression. Those regions where the regression was not meaningful, significance >0.05, do not have the least squares model indicated. Regressions for cluster analysis regions (Table 5) had lower R values (0.46873-0.77617) and higher significance indices than those for ratio analysis regions (Table 6) (0.70091-0.97991), indicating less significant cluster analysis regressions. Slopes of the linear regression models decreased successively (95.71, 35.17, 27.18, 23.86) through Regions C, A, D, and B, respectively, for the cluster analysis, and (125.77, 79.97, 68.75, 57.70, 47.56, 41.06) through Regions 1, 2, 4, 3, 6, and 5, respectively, for the ratio analysis.

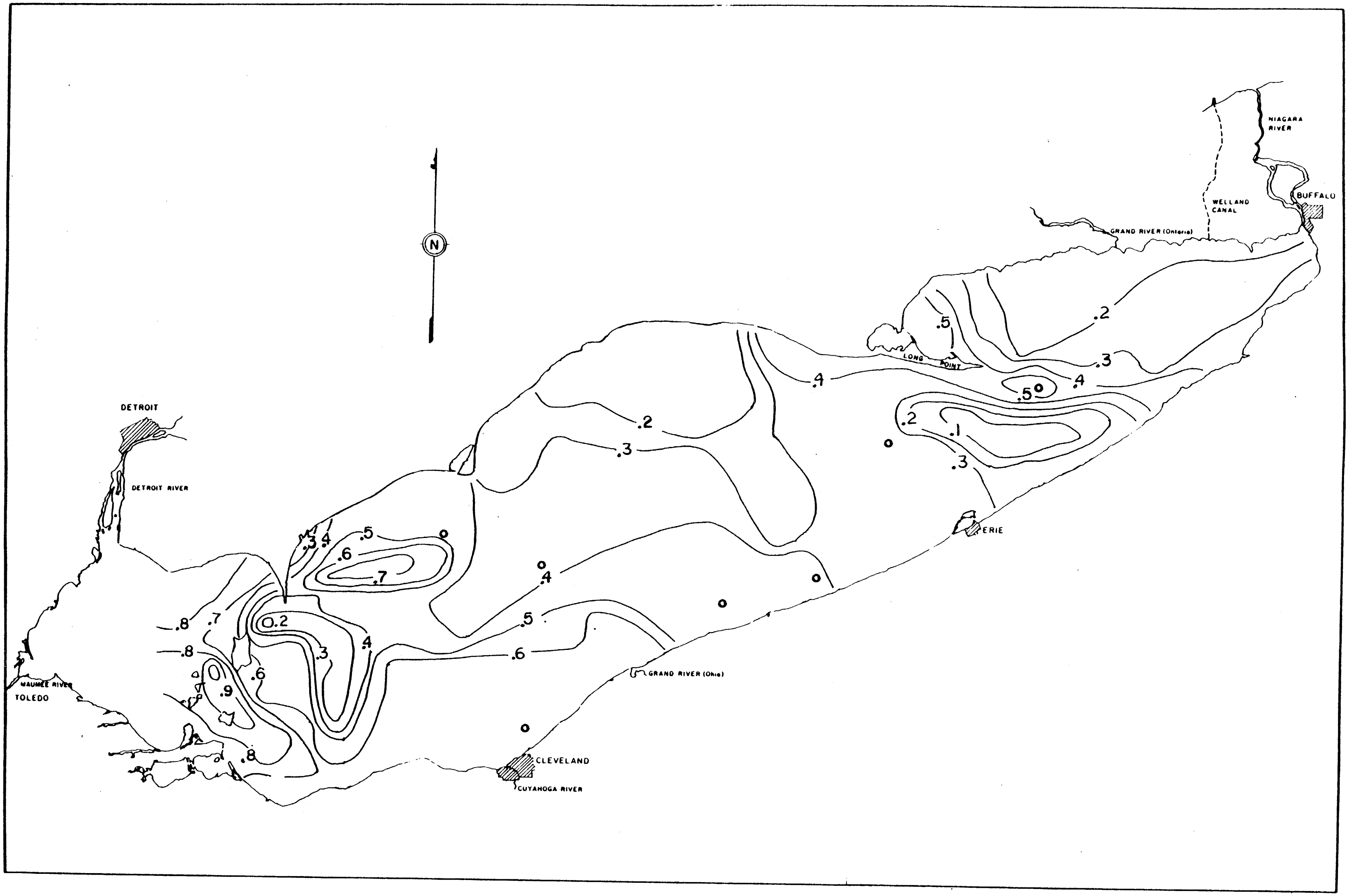

FIG. 7. Degree of sediment oxidizability as indicated by ratio of mixed sediment oxygen uptake rate to percentage of organic matter in Lake Erie in 1963.

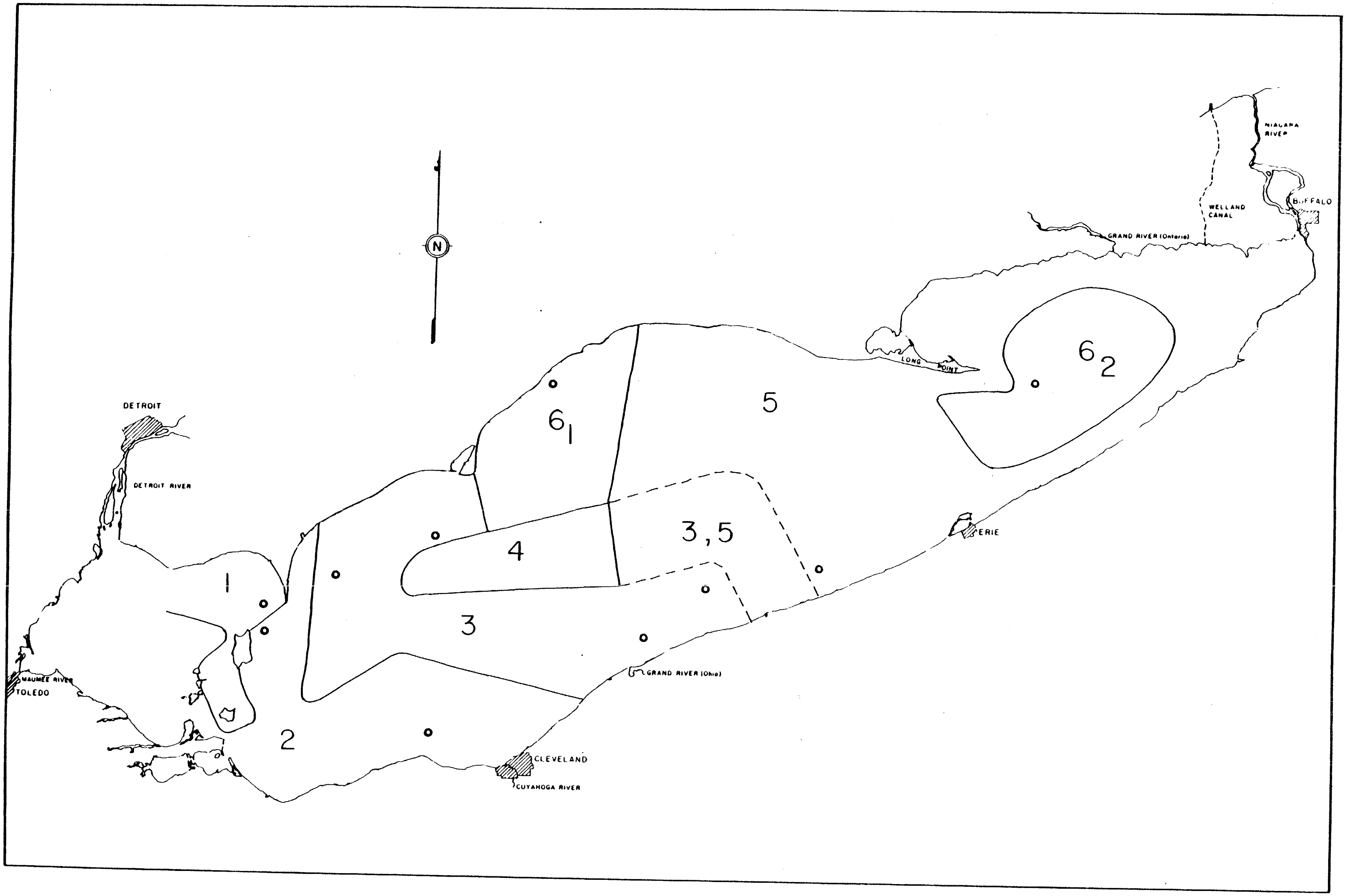

FIG. 8. Regions of similar sediment oxidizability as determined by ratio of mixed sediment oxygen uptake rate to percentage of organic matter in Lake Erie in 1963.

TABLE 5. Oxygen uptake of mixed sediment related to percent organic matter for regions determined by cluster analysis in Lake Erie 1963. Y = $\mu g\ O_2$ consumed/gm sediment/5 minutes; X = % organic matter.

Regions A and A1. Stations 2-6, 8-14, 16, 19, 21, 23, 25-31, 14, 20, 32, 43, 52, 76, 36-41, 44-49, $50_{1\ 2}$, 51, $53_{1\ 2}$, 67, 68, 75, 77, 113, 114 (omitting 83, 109); N = 46.

Y = 252.96 + 35.175x   R = 0.46873   Significance = 0.0010

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	7.	24.	15.3	5.0
% Organic	4.22	10.19	7.735	1.558
Mixed Uptake [μgO_2/gm sed/5 min]	271.	754.	525.0	116.9
Average Core Uptake [$\mu gO_2/cm^2$/hr]	4.99	8.29	6.635	0.767
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.42	1.03	0.692	0.144

Regions B and B1. Stations 15, 17, 22, 33-35, 78, 79, 84, 85, 101-103 (omitting 81, 104, 108); N = 14.

Y = 54.403 + 23.856x   R = 0.53262   Significance = 0.0499

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	9.	23.	16.9	5.0
% Organic	1.28	8.76	5.208	2.09
Mixed Uptake [μgO_2/gm sed/5 min]	48.	315.	178.6	93.6
Average Core Uptake [$\mu gO_2/cm^2$/hr]	5.52	8.33	6.780	0.801
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.10	0.53	0.350	0.120

TABLE 5. (Continued).

Regions C1, C2, and C3. Stations 49_2, 53_1, 54, $55_{1\ 2}$-58, 63, 64, 69, 74, $80_{1\ 2}$, $82_{1\ 2}$, 83_2, 91, 92, 94, 96, 110, 112 (omitting 14, 72, 81, 83, 153); N = 23.

$Y = -475.85 + 95.71x$ R = 0.57601 Significance = 0.0040

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	17.	24.	21.0	1.9
% Organic	7.37	10.76	9.388	0.936
Mixed Uptake [μgO_2/gm sed/5 min]	171.	706.	422.7	155.5
Average Core Uptake [$\mu gO_2/cm^2/hr$]	3.20	5.74	4.531	0.769
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.20	0.75	0.447	0.144

Region D. Stations 86, 87, 97, 111, 115, 116, 118, 120, 122, 128, 129, 131, 136, 138, 143, 145, 147-149, 152, 154, 155 (omitting 20, 32, 43, 72, 99, 100, 119, 153, C-9); N = 22.

$Y = -79.189 + 27.178x$ R = 0.77617 Significance 0.0000

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	9.	29.	20.0	5.5
% Organic	1.12	7.52	3.536	1.778
Mixed Uptake [μgO_2/gm sed/5 min]	15.	218.	95.3	62.3
Average Core Uptake [$\mu gO_2/cm^2/hr$]	1.68	4.54	3.170	0.755
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.05	0.53	0.270	0.117

Region E. Stations 123, 124, 127, 132, 133, 135, 137, 139-142, C-5, C-7 (omitting 134, 150); N = 13.

Regression not meaningful.

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	27.	62.	42.5	9.7
% Organic	3.64	9.32	7.196	1.750
Mixed Uptake [μgO_2/gm sed/5 min]	31.	446.	162.7	129.1
Average Core Uptake [$\mu gO_2/cm^2/hr$]	1.29	4.38	2.559	0.970
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.06	0.54	0.222	0.161

TABLE 6. Oxygen uptake of mixed sediment related to percent organic matter for regions determined by ratio of mixed sediment oxygen uptake rate to percent organic matter in Lake Erie, 1963. Y = μg O_2 consumed/gm sediment/ 5 minutes; X = % organic matter.

Region 1. Stations 5, 6, 9, 10, 12, 14, 19 (omitting 18); N = 7.

$Y = -209.12 + 125.77x$ R = 0.97122 Significance 0.0003

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	9.	13.	10.7	1.3
% Organic	4.22	7.20	5.969	1.080
Mixed Uptake [μgO_2/gm sed/5 min]	340.	742.	541.6	139.9
Average Core Uptake [$\mu gO_2/cm^2/hr$]	4.99	7.97	6.350	0.982
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	0.79	1.03	0.897	0.081

Region 2. Stations 2-4, 8, 11, 13, 15, 16, 20-23, 25-32, 48, 49_1, $50_{1\ 2}$, $51\text{-}55_{1\ 2}$, 72, 114 (omitting 17, 53); N = 32.

$Y = -72.798 + 79.972x$ R = 0.96044 Significance = 0.0000

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	7.	22.	13.9	4.0
% Organic	0.42	10.37	6.827	2.573
Mixed Uptake [μgO_2/gm sed/5 min]	8.	754.	473.2	214.3
Average Core Uptake [$\mu gO_2/cm^2/hr$]	2.56	8.29	6.235	1.373
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	0.06	0.85	0.636	0.195

TABLE 6. (Continued).

Region 3. Station 33-36, 38-41, 46, 47, 56-58, 68, 69, 74,-76, 78-82, 84, 85, 110-112 (omitting 37, 43, 83, 113); N = 30.

Y = -95.766 + 57.698x   R = 0.90501   Significance 0.0000

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	14.	24.	20.5	2.7
% Organic	2.56	10.76	8.177	2.224
Mixed Uptake [$\mu g O_2$/gm sed/5 min]	77.	648.	376.0	141.8
Average Core Uptake [$\mu g O_2/cm^2/hr$]	3.43	8.33	5.860	1.361
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.25	0.60	0.448	0.085

Region 4. Stations 44, 45, 66, 77; N = 4.

Y = -6.8055 + 68.745x   R = 0.97991   Significance 0.0201

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	22.	24.	22.5	1.0
% Organic	7.37	9.02	8.365	0.708
Mixed Uptake [$\mu g O_2$/gm sed/5 min]	505.	623.	568.3	49.7
Average Core Uptake [$\mu g O_2/cm^2/hr$]	5.98	6.33	6.115	0.157
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.66	0.69	0.680	0.014

Region 5. Stations 78, 79, 81, 84-87, 99-104, 107, 108, 110, 111, 114-118, 120, 122, 124, 127-129, 131, 132, 136, 138, 143, 147-153 (omitting 109); N = 39.

Y = -24.174 + 41.064x   R = 0.88539   Significance = 0.0000

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	9.	46.	21.2	8.1
% Organic	0.25	7.37	3.512	1.881
Mixed Uptake [$\mu g O_2$/gm sed/5 min]	12.	313.	120.0	87.3
Average Core Uptake [$\mu g O_2/cm^2/hr$]	0.82	8.33	4.127	1.806
Ratio $\frac{\text{[mixed uptake]}}{\text{[100(\% organic)]}}$	0.11	0.76	0.333	0.134

TABLE 6. (Continued).

Regions 6_1 and 6_2. Stations 63, 64, 91, 92, 94, 96, 123, 133, 135, 137, 139-142, 145, 154, C-5 (omitting 97-134) N = 18.

$Y = -199.00 + 47.561x$ $R = 0.70091$ Significance = 0.0036

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	20.	55.	32.4	11.2
% Organic	4.86	9.60	7.868	1.385
Mixed Uptake [μgO_2/gm sed/5 min]	31.	355.	172.7	102.3
Average Core Uptake [$\mu gO_2/cm^2/hr$]	1.29	4.98	3.182	1.186
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	0.06	0.38	0.209	0.109

Region 6_1. Stations 63, 64, 91, 92, 94, 96 (omitting 92); N = 6.

Regression not meaningful.

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	20.	24.	21.7	1.5
% Organic	7.96	9.60	8.753	0.637
Mixed Uptake [μgO_2/gm sed/5 min]	171.	355.	256.7	67.9
Average Core Uptake [$\mu gO_2/cm^2/hr$]	3.20	4.98	4.345	0.660
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	0.20	0.38	0.292	0.071

Region 6_2. Stations 123, 133, 135, 137, 139-142, 145, 154, 155, C-5; N = 12.

Regression not meaningful.

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Depth [meters]	27.	55.	37.8	10.0
% Organic	4.86	9.32	7.425	1.462
Mixed Uptake [μgO_2/gm sed/5 min]	31.	327.	130.7	91.2
Average Core Uptake [$\mu gO_2/cm^2/hr$]	1.29	3.72	2.601	0.933
Ratio $\frac{[\text{mixed uptake}]}{[100(\%\ \text{organic})]}$	0.06	0.37	0.168	0.103

DISCUSSION

Organic Deposition

Deposition patterns of organic matter depend primarily on source locations and circulation. Due to the highly productive nature of Lake Erie, the water column is a very important source of organics. Productivity increases in a westerly direction. This phenomenon is attributed to several factors, including a high degree of mixing and nutrient regeneration in the shallow western basin. Additionally, there is a large influx of allochthonous nutrients from major rivers, especially the Detroit River, discharging into western Lake Erie.

Keeping these sources in mind, deposition will also depend on how far and in which direction this organic matter is transported. In the western basin and along the southern shore, a generally eastward flow predominates (Hartley 1968), with a strong southerly current just east of the island area (Figure 9).

In the deeper portions of the lake, a distinct two-layer circulation pattern exists, often in opposing directions (Hartley 1968). This is reasonable when the massive eastward surface flow (Figure 10), resulting from the prevailing westerly winds, is considered to require a return flow upwind. Seiches thus produced could be an important factor in resuspending sediments below effective wave depths.

Assuming bottom currents as having the predominant effect on deposition and resuspension, it can be seen that % organic matter (Figure 3) corresponds well with Hartley's circulation pattern (Figure 9). Areas of high current intensity show little deposition (e.g. Pelee Passage), as well as those shallow areas exposed to wave action. Organic sinks occur in the middle of gyres (e.g. south of Pte. Aux Pins), in areas of opposing currents (e.g. north of Sandusky,

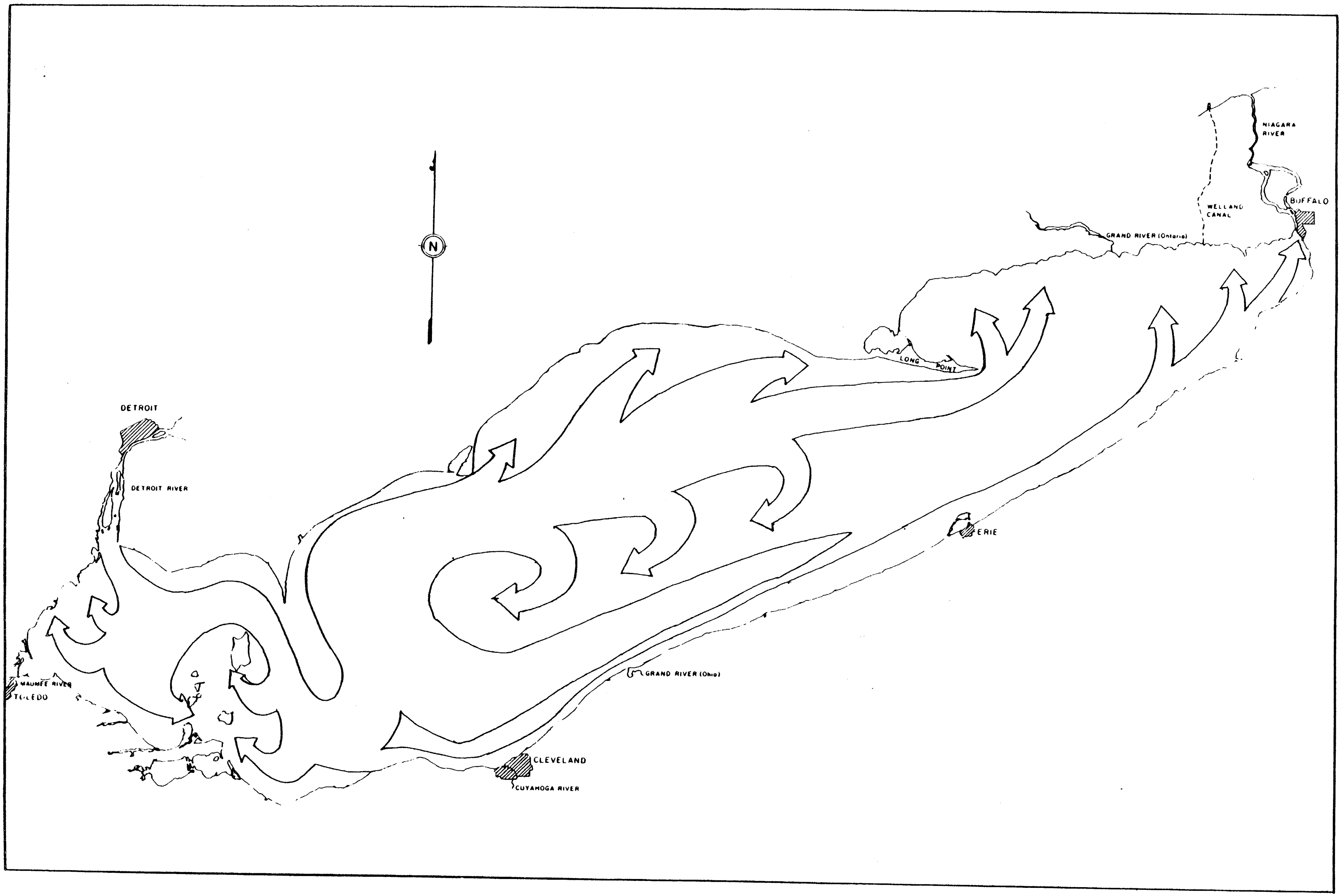

FIG. 9. Bottom currents of Lake Erie (from R. P. Hartley 1968).

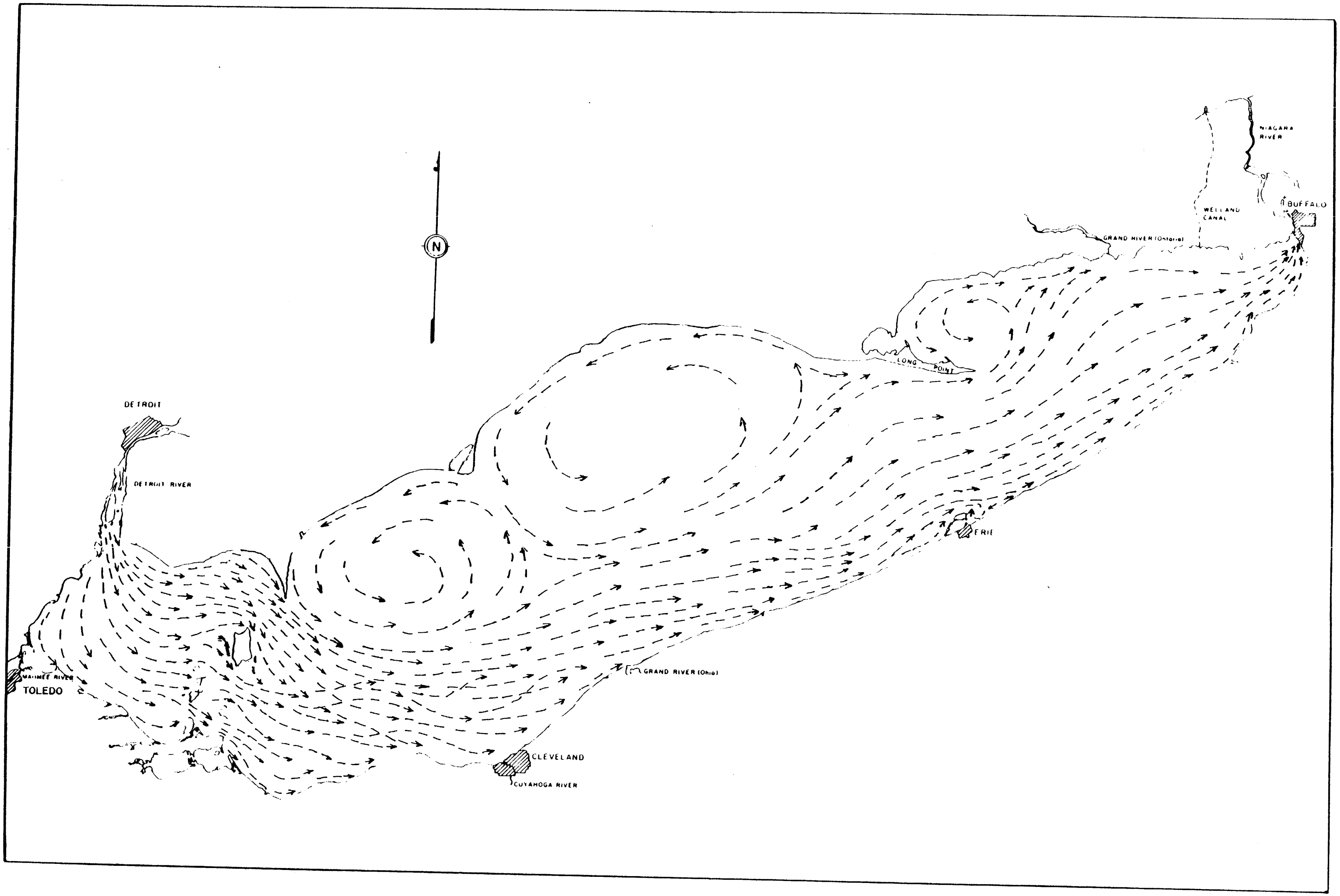

FIG. 10. Surface currents of Lake Erie (J. F. Carr, unpublished).

northeast of Cleveland), or in the deep hole of the eastern basin. The broad tongue of high organic content extending east along the south shore of the central basin implies a wider eastward flow than Hartley's circulation pattern suggests. The large region of low organic content in the northeast corner or the central basin is possibly a result of low input rather than resuspension.

Despite these relationships to wave energetics, % organic matter had poor correlation to depth. Indeed, the entire western basin is not in equilibrium with respect to wave energy and sediment particle size. The presence of these fine particulates indicates that input overwhelms redeposition processes (Thomas et al. 1976).

Mixed Sediment Oxygen Uptake Rates

The mixed sediment oxygen uptake rate is considered to represent the maximum possible oxygen demand exerted by the sediments on the overlying water. Naturally, such optimal conditions for oxidation would not exist except in extreme storm surges and the resulting seiches. This extremely fast (within 5 minutes) uptake of oxygen was probably a chemical oxidation of the organic matter and any other reduced substances present, such as iron and manganese ions.

In spite of the artificiality of this method, the strong correlation to % organic matter suggests its usefulness as an indicator of oxygen stress due to sediments. Also, the relationship between these has an intriguing stipulation. While high and low uptake indicate high and low organic content, respectively, high % organic matter does not necessarily indicate high oxygen uptake. Possibly, older organic matter exists that has already undergone a degree of oxidation and therefore exerts a much lower oxygen demand.

With this relationship in mind, an attempt was made to separate the lake

into regions of similar organic type. The cluster analysis was done to provide a means of dividing the lake into these regions based on all variables measured: depth, % organic matter, mixed sediment oxygen uptake, all core oxygen uptake rates, and the ratio value (Figure 6). The ratio value was devised to get an index of the oxidizability of the organic matter at each station individually, as well as to allow a more refined separation into regions based only on those variables directly of interest (Figure 8).

The graphs of regions thus determined show a characteristic % organic matter coupled with a distinctive rate of oxygen uptake. The slope of the regression line is of particular interest in that it assesses the relative oxygen demand of the organic matter in the sediments.

Especially for the regions determined by ratio similarity (Figure 8), there exists an easterly decrease in regression slope through Regions 1, 2, 4, 3, 6, and 5 (Table 6). This indicates an easterly decrease in organic oxidizability and supports the theory that much of the organic matter originates in the western basin. As it is carried eastward by the previously mentioned circulation, this organic matter is oxidized and exerts a lesser oxygen demand upon settling.

It can be seen that in Regions 1 and 2 the organic matter present exerts a high degree of oxygen demand, although the regions are not always high in organic content. Region 3, on the other hand, is further removed from the source and the organic matter has a moderate degree of oxidizability. Both Regions 2 and 3 correspond well with circulation patterns, trailing off to the east on both the north and the south coastlines. Region 4 corresponds to the middle of the gyre proposed by Hartley (1968), and is probably a sink characterized by high organic content. This is adequate cause for medium high oxygen uptake despite the relative remoteness from sources. In both Regions 5

and 6, there is low oxygen uptake due to the distance from organic sources. There are, however, distinctions based on the % organic matter; notably, the eastern basin (Region 6_2) has a very high organic content, while Region 5 (surrounding it) behaves similarly but has much less organic matter present.

The cluster analysis does not yield such a clear picture. This is because the analysis is much more encompassing, perhaps too much so, giving disproportionate consideration to core uptake values. Nevertheless, the stations thus clustered did exhibit fairly tight clumping when mixed uptake was plotted against % organic matter.

The least square regressions done on these graphs were not quite as significant as the ratio plots (Table 5). With the exception of the Region A and C reversal, however, there did exist an easterly decrease in slope, the significance of which was discussed previously. Also, the easterly trailing off of regions is again seen on the north and south coastlines (Figure 6). The eastern basin is equally well delineated. Regions A and C extend much further east than the corresponding ratio Regions 2 and 3.

Core Oxygen Uptake Rate

The core uptake rate, as opposed to mixed sediment uptake, was supposed to represent a minimal oxygen demand the sediment could exert on the overlying water. In the process of centrifuging twice, the normally loose sediment was compacted, eliminating interstitial spaces.

The slower uptake, compared to mixed sediment uptake of oxygen, was most likely dominated by a biological oxygen demand due to bacterial respiration.

The wide range of values obtained for the 2-hour incubations compared to the close agreement between the 4- and 6-hour incubations suggests that the former had insufficient time for the uptake rate to equilibrate, while the good

correlation between the latter two indicates that 4 hours was probably an adequate incubation duration. This is supported by the observation that, while none of the core measurements correlated well with the other variables, the 4-hour incubation did so better than the others.

The high correlation coefficient between each incubation period and the average core oxygen uptake demonstrates that the method was consistent. Unfortunately, the lack of correlation to other parameters made it impossible to evaluate this procedure as a measurement of oxygen demand exerted by the sediments.

BOD Determination

Unfortunately, BOD determinations, as well as other physical and chemical parameters, could not be included in the analysis because data were not present for all of the stations considered. However, based on a 5-day BOD of approximately 1 mg/L/5 days, it would require 46 days to deplete the hypolimnion of oxygen, while this actually occurred in about 20 days after stratification. This indicates that the BOD of the overlying water is insufficient to be the major factor in oxygen depletion (Carr et al. 1963).

CONCLUSION

The results of this research are primarily consistent with the conclusions of Project Hypo (Burns and Ross 1972c). Sediment uptake is seen to be more than capable of depleting the hypolimnion of oxygen. This is made evident by comparing aerial uptake rates. *In situ* measurements of 0.40, 0.31, and 0.39 gm O_2/m^2/day were obtained by Lucas and Thomas (1971), Blanton and Winklhofer (1972), and Burns and Ross (1972c), respectively. The average core uptake rate

of 4.987 $\mu g/cm^2/hr$ corresponds to 1.20 gm $O_2/m^2/day$. This suggests that, rather than representing minimal uptake as previously assumed, core rates are in excess of those occurring naturally. Apparently the disturbance of the oxygen gradient over sediment depth brought reduced substances to the sediment-water interface and was sufficient cause for increased uptake in spite of compaction.

Unfortunately, the values obtained by the mixed sediment method are not comparable to other studies, in that oxygen uptake is expressed per gram sediment as opposed to aerial or volumetric uptake.

Menon et al. (1972) reported that bacterial oxygen uptake was only 52.6% of theoretical maximum. This suggests that oxygen could have been at limiting concentration at the sediment interface and explains the increased oxygen uptake observed in this study by sediments exposed to oxygen-saturated water.

While BOD values were shown to be insufficient to account for oxygen depletion in the hypolimnion, Burns and Ross (1972d) more clearly illustrated the importance of the sediments in oxygen depletion. The estimated 328 x 10^7 moles O_2 consumed by the sediments of the central basin was 81% of the total oxygen consumed from the hypolimnion. Also, 96% of the aerobic heterotrophic bacteria in the hypolimnion was found on the bottom. Approximately 88% of the oxygen consumed is due to this bacterial respiration and oxidation of organic matter; the remaining 12% is consumed by reduced metallic species.

The assertion that there is a large flux of organic matter from west to east is supported by Burns et al. (1976). Additionally, the depletion pattern reported by Burns and Ross (1972c) is in agreement with this study, the western third of the lake and the southern coastline of the central basin having the highest oxygen uptake rates.

While this research did not yield oxygen uptake values comparable with

those measured *in situ* by other investigators, it did produce information that clarifies oxygen depletion processes in Lake Erie. The use of mixed sediment uptake versus % organic matter regression is instrumental in determining the degree to which organic matter in the sediment consumes oxygen.

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